

Broiler litter ammonia emissions near sidewalls, feeders, and waterers^{1,2}

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ABSTRACT Ammonia (NH₃) volatilized from broiler litter diminishes indoor air quality, which can potentially decrease bird productivity. Emissions of NH₃ exhausted from broiler houses pose environmental concerns for ecosystem biodiversity, aquatic nutrient enrichment, and particulate formation in the atmosphere. Research was conducted sampling litter (rice hull base) in 3 tunnel-ventilated commercial broiler houses during wk 3 (mid-growout) of 6 flocks. The purpose was to assess NH₃ generated near the sidewalls, waterers, and feeders. Litter samples (100 g) were placed in chambers receiving constant air flow. Boric acid (H₃BO₃) titration each 24 h for 4 d was used to determine NH₃ volatilized from the samples. Litter located near waterers emitted the most cumulative NH₃ (approximately 12.3 mg of N·kg of litter⁻¹·h⁻¹) with less NH₃ associ-

ated with feeders and sidewalls (2.9 to 7.6 mg of N·kg of litter⁻¹·h⁻¹). Moisture content of litter samples was greatest at waterers (45%) followed by sidewalls (26%) and feeders (20%). In addition, litter pH at the sidewalls and feeders could be predicted by linear equations associated with the number of flocks on the litter. At the waterers, litter pH was differentiated based on the half of house where higher litter pH existed in the nonbrood half (8.55 vs. 8.13). The results indicate that controlling NH₃ near watering lines to a level consistent with feeding lines and near the house wall could reduce NH₃ generated by 38 to 77%. These findings support efforts for NH₃ control at mid-growout, especially considering zone litter treatments near waterers and appropriate attention to waterer management.

Key words: ammonia, broiler, litter, rice hull, waterer

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INTRODUCTION

Broiler chicken production in the United States in 2011 totaled more than 8.6 billion chickens. Approximately 58% of broilers were produced in Georgia, Arkansas, Alabama, North Carolina, and Mississippi (National Agricultural Statistics Service, 2012). Optimal delivery of water and feed to broiler chickens and a myriad of other factors interrelate and contribute to grower and industry profitability. One such factor is the litter covering broiler house floors; its quality and management are prime contributors to bird well-being. Because growers are challenged by natural processes that generate ammonia (NH₃) from accumulated fecal matter as litter ages, a better understanding of NH₃ volatilization relative to specific locations (i.e., around

feeders and waterers) within houses can provide useful insights for more effective management.

Complications from NH₃ exposure in animal rearing facilities have long been recognized. These include respiratory disease (exposure 200 ppm, Anderson et al., 1964), eye damage (exposure 50 and 75 ppm, Miles et al., 2006a), inefficient feed conversion (exposure 100 ppm, Charles and Payne, 1966), and decreased BW (exposure 50 and 75 ppm, Miles et al., 2004; exposure 50 ppm, Reece et al., 1981). More recently, environmental issues relative to gaseous emissions from houses are becoming a concern for the animal production industry (Moore et al., 2011) due to the possibilities of compromising terrestrial bio-diversity, inducing aquatic nutrient enrichment, and diminishing air quality (Asman et al., 1998; Council for Agricultural Science and Technology, 2002; Mukhtar et al., 2003). One method of reducing NH₃ concentrations in houses is using chemical litter treatments, which generally act by lowering litter pH. Compared with no litter treatment, reductions of 36 to 90% can be achieved using chemical treatments (Shah et al., 2006). However, chemical effectiveness varies with type and application rate and, generally, may become ineffective after a few days to a few weeks. Animal nutrition research is being conducted to re-

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duce excess N excretion and thereby reduce NH_3 emissions (Council for Agricultural Science and Technology, 2002) as another mitigation strategy. In addition, NH_3 scrubbers are emerging in the United States to treat exhaust air from broiler houses (Lahav et al., 2008). Use of scrubbers would satisfy environmental concerns, but would not address the house interior atmosphere. As with most new technologies, widespread implementation will not be immediate, and most of the industry will need to hone existing technology and house management for the best NH_3 control.

Factors pertinent to litter and NH_3 generation include physical and chemical litter properties (temperature, moisture, pH, and N content), type of original bedding material, between flock management such as windrowing and decaking, effects and frequency of top dressing, and spatial characteristics of gas evolution within houses. Elliott and Collins (1982) indicated an increase in NH_3 with temperature, moisture, and pH. Coufal et al. (2006b) cited moisture and pH as more readily manipulated in houses than temperature, which is controlled for bird comfort. Separately, for reducing N volatilization when reusing litter (rice hull base and top dressing), Coufal et al. (2006a) recommended that top dressing not be used. A comparative laboratory study of organic vs. inorganic bedding materials reported that wood shavings and rice hulls produced less NH_3 than sand and vermiculite and increases in litter moisture increased NH_3 produced for all materials (Miles et al., 2011b). Spatial characterization of litter relative to NH_3 volatilization has shown higher litter moisture content near waterers (Tasistro et al., 2004), increased NH_3 volatilization just outside water lines (Brewer and Costello, 1999), and that litter between feeders and waterers can be consistently differentiated from surrounding samples from mid to late growout, but the magnitude of moisture is not reliably higher or lower between winter and summer (Miles et al., 2011a). The present study is more similar to Tasistro et al. (2004) in that NH_3 measurements were conducted on litter samples removed from the houses rather than performed in houses on undisturbed litter such as Brewer and Costello (1999) and Miles et al. (2011a). The current research is explicitly differentiated from Tasistro et al. (2004) by having tunnel ventilation from 11 (1.3 m) fans vs. cross-flow ventilation from 4 (91 cm) fans; being conducted in 3 larger commercial houses with footprint 15.2×152 m vs. a single house with dimensions of 10.5×120 m; reusing rice hulls over 6 flocks vs. a single growout on sawdust and wood shavings; conducting measurements at mid-flock over different seasons vs. at the end of a winter flock; and using 100-g litter samples in an acid trap system vs. 0.5-g litter samples suspended in 50-mL water with an ion selective probe.

The objective of the current research was to determine the temporal changes in NH_3 generation from rice hull litter located specifically in proximity to broiler house sidewalls, feeders, and waterers at mid-growout during 6 flocks on reused litter. The research began

in pristine houses where birds had never been placed, providing an opportunity to test background soils and fresh bedding materials for NH_3 generation. No other works were found in the literature that have studied the influence of these house attributes for modern tunnel-ventilated houses through this extended period of litter reuse. The goal was to provide integrators with a decision-making tool for managing reused litter within houses relative to NH_3 emissions.

MATERIALS AND METHODS

Experimental Design

To compare NH_3 generation of rice hull litter relative to location and half house brooding effects, a factorial arrangement of treatments was tested in 3 houses. Six trials (flocks 2, 3, 4, 5, 7, and 9) evaluated litter sampled at 3 locations (sidewalls, feeders, and waterers) in the brood half and nonbrood half in each of the broiler houses, yielding a balanced factorial design of 6 treatments. For each treatment, 2 duplicate samples were tested for NH_3 volatilization during each trial. The average of the duplicate samples was statistically analyzed.

Litter Sampling and Analyses

Access to a new commercial farm in Mississippi afforded a unique opportunity to investigate the progression of NH_3 volatilization at selected locations within new houses where birds had never been grown. Construction on the 6-house broiler farm was completed in 2009. Each 15.2×152.4 m (50×500 ft), solid-side-wall house had the following components: 3 automated feeder lines with nipple waterer lines on both sides of the feeders, an insulated drop ceiling, box inlets near the ceiling, brood heaters down the center of the entire house, evaporative cooling pads on each side at the front of the house (brood half, west end), two 0.91-m (36 in) fans in the west end for minimum ventilation, eleven 1.3-m (52 in) fans on the east end (nonbrood half), capacity for up to 30,000 chicks at placement, rice hull bedding, and migration fencing (division of the house into quarters, lengthwise). The houses were operated in all-in/all-out mode, and each growout was approximately 53 d. For each house and after each flock, decaking followed by top dressing with rice hulls was performed during a 2- to 3-wk layout. At the beginning of each flock, chicks were placed in the west end or brood half of the house for variable time periods determined by the grower's preference.

Litter samples were collected at the northern sidewall, waterer line, and feeder line in 3 of the 6 broiler houses (Figure 1). Five samples for each treatment were obtained at equally spaced intervals along a 45.7-m (150 ft) lengthwise section of both the brood and nonbrood halves of each house. At each interval, samples were picked up by a gloved hand from approxi-

Samples were collected at the end of flocks 1, 2, and 3 (data not shown) and at 3 wk into the growout for flocks 2, 3, 4, 5, 7, and 9. Those flocks corresponded to sampling dates in June, August, and December of 2009 and February, June, and November of 2010. The mid-flock (3 wk) time was chosen to ascertain the potential of NH_3 release during this phase of the growout as well as to avoid the greater degree of cake expected near feeders and waterers later in the flock. Qualitative

NH₃ Measurement

Litter samples (2 duplicates from each treatment bag) were placed in 1-L chambers receiving humidified air that was exhausted into boric acid solution (H_3BO_3). The laboratory system was designated the chamber acid trap (**CAT**) system, and was described in greater detail in a previous publication (Miles et al., 2008a). Briefly, compressed, humidified air passed through the 1-L containers, which housed 100-g litter samples. For each chamber, the air containing volatilized NH_3 exhausted into a series of 2 flasks each containing 30 mL of H_3BO_3 (Miles et al., 2008a). Each 24 h for 4 d, the series trap solutions for a treatment were combined and titrated with hydrochloric acid (HCl) to determine the NH_3 captured (mg of N). The system has the capacity



Table 1. Mean cumulative NH_3 , litter NH_4^+ , moisture content, and pH from reused rice hull litter samples (2 to 9 flocks) at the sidewall, waterer, and feeder in tunnel ventilated commercial broiler houses

Item	Sample location			SEM
	Sidewall	Waterer	Feeder	
Cumulative NH_3 [mg of N/(kg of litter·h)]				
Brood	5.68 ^b	12.3 ^a	4.52 ^b	0.78
Nonbrood	7.57 ^b	12.2 ^a	2.85 ^c	0.65
NH_4^+ (mg/kg of litter)	2,399 ^b	3,119 ^a	2,632 ^b	108
Moisture (%)	25.8 ^b	45.2 ^a	20.0 ^c	1.12
pH				
Brood		8.13 ^b		0.11
Nonbrood		8.55 ^a		
Whole house	8.9715 – 0.0574 × (flock)		8.9 – 0.1055 × (flock)	

^{a–c}Means within a parameter lacking a common letter differ significantly ($P \leq 0.05$).

to use 48 chambers during a trial. During this study, 36 chambers were used for litter samples (3 houses × 6 locations × 2 duplicate samples) and 3 chambers served as blanks (negative controls) to ensure no contamination of incoming supply air. During the 6 trials, the average flow rate to each chamber in the system was 112 mL/min (SD of 10 mL/min). House pad (soil) samples and fresh rice hull bedding were evaluated in the CAT system before the litter trials.

Statistical Analyses

The data were checked for normality followed by ANOVA using procedures of SAS (SAS Institute, Inc., 2003). PROC UNIVARIATE was used to determine if the responses for NH_3 generation were normally distributed. No abnormalities were associated with the distributions; thus, no transformations of the responses were needed for further evaluation of the data. Least significant difference (PROC GLIMMIX) means separation procedures were used to determine significance of NH_3 response, as well as to determine changes in litter NH_4^+ , moisture and pH relative to flock, half of house (brood or nonbrood), and location (sidewalls, waterers, or feeders). House was treated as a random variable. The significance level declaration was $P = 0.05$. Both daily NH_3 volatilization and cumulative NH_3 (total volatilized during the 4 d experiment in the CAT system) were analyzed. Although simplified by analyzing by location, initially, 9 significant effects were present in the daily NH_3 volatilization. Because of the complexity and lack of utility of the quadratic responses to predict daily NH_3 for the sidewalls, waterers, or feeder locations, these equations are not reported.

RESULTS AND DISCUSSION

Mid-flock litter characteristics of 1) cumulative NH_3 , reported as a flux of mass N per kg of litter per h (mg of N·kg of litter⁻¹·h⁻¹); 2) litter NH_4^+ (mg/kg of litter); 3) moisture content (%); and 4) pH are given in Table 1. Because the farm construction was recently completed and the broiler houses were new, a unique opportunity arose to test background levels of NH_3

in the house pad (soil) samples and unused rice hulls. House pad samples (13.3% moisture with pH = 7.67) emitted no NH_3 in the CAT system. Total generation of NH_3 from the unused rice hulls was 0.18 mg of N·kg of rice hulls⁻¹·h⁻¹, or between 1 and 6% of the mean overall litter-generated NH_3 . Fresh rice hulls had a moisture content of 11% and a pH = 6.46. Mid-growout litter samples during 6 flocks gave the following overall results for litter moisture content and pH, respectively, of the reused rice hull litter: sidewalls, 25.8 ± 2.9% and 8.7 ± 0.4; waterers, 45.2 ± 8.8% and 8.3 ± 0.5; and feeders, 20 ± 3% and 8.4 ± 0.4.

During the mid-flock assessment, litter moisture content was significantly affected by location ($P < 0.0001$). Moisture contents during mid-flock at the sidewalls, waterers, or feeder locations are given in Table 1, where litter at waterers had the greatest moisture content, followed by sidewalls, then feeders. Analysis of litter pH indicated significant interaction of flock × location ($P = 0.0107$) as well as significant effects of sampling location ($P = 0.0002$), half of house ($P = 0.0169$), and flock ($P = 0.0008$). Separating by location and confining the analysis to significant components resulted in linear equations to predict pH based on the number of flocks for feeder and sidewall litter pH (Table 1). However, for the waterers, only half of the house was significant ($P = 0.0105$), which indicated mean pH was 8.13 in the brood half and was significantly lower than the nonbrood half of the house (8.55). Litter NH_4^+ mean separation was similar to moisture content, straightforward as significantly affected by location ($P < 0.0001$). Waterer litter NH_4^+ was greatest followed by the feeders and sidewalls that did not appear different (Table 1).

Mean cumulative NH_3 released from litter at sidewalls, waterers, or feeders during mid-flock for 6 flocks on reused rice hull bedding is presented in Table 1. Two significant effects on total NH_3 from the litter samples included location ($P < 0.0001$) and a half house × location interaction ($P = 0.0497$). Responses were separated based on brood and nonbrood half of house. In the brood half, sidewall and feeder litter NH_3 appeared similar at 5.68 and 4.52 mg of N·kg of litter⁻¹·h⁻¹. At 12.3 mg of N·kg of litter⁻¹·h⁻¹, the NH_3 associated with the waterers in the brood half of the house was

greater than the brood-sidewalls and brood-feeders, but did not appear different than the nonbrood-waterers ($12.2 \text{ mg of N} \cdot \text{kg of litter}^{-1} \cdot \text{h}^{-1}$). The NH_3 volatilized from the nonbrood-sidewalls ($7.57 \text{ mg of N} \cdot \text{kg of litter}^{-1} \cdot \text{h}^{-1}$) was less than the nonbrood-waterers and statistically analogous to the brood-sidewall and brood-feeder NH_3 generation. The least amount of NH_3 was generated by the nonbrood-feeder litter ($2.85 \text{ mg of N} \cdot \text{kg of litter}^{-1} \cdot \text{h}^{-1}$). These results compare with rice hull litter-generated NH_3 at $14.3 \text{ mg of N} \cdot \text{kg of litter}^{-1} \cdot \text{h}^{-1}$ in a similar laboratory CAT system after 4 flocks (Moore et al., 1996).

The following discussion provides analogies between the current study results and previously reported spatial characterization of broiler litter. It should be stressed that the earlier spatial studies differed in overall objectives and in NH_3 measurement methodology. Thus, direct comparison of NH_3 emissions is not viable, but inferences based on trends are discussed.

Litter moisture content results from the present study (reused rice hulls) were comparable with litter moisture content results (after one flock on sawdust and wood shavings in a cross-flow ventilated house in Georgia) reported as feeder $17.4 \pm 2\%$ and waterer $54.6 \pm 5\%$ in the first published intensive spatial broiler litter study (Tasistro et al., 2004). They measured litter $\text{NH}_3\text{-N}$ using an ion selective electrode in a deionized water solution, finding brood NH_3 at feeders = $540 \pm 150 \text{ mg of NH}_3\text{-N/kg of dry litter}$ and at waterers = $690 \pm 340 \text{ mg of NH}_3\text{-N/kg of dry litter}$. The other half of the house in the Tasistro et al. (2004) study had no brooders with feeder = $440 \pm 40 \text{ mg of NH}_3\text{-N/kg dry litter}$ and waterer = $450 \pm 230 \text{ mg of NH}_3\text{-N/kg of dry litter}$. Litter pH measurements were brood-feeder 7.86 ± 0.47 and brood-waterer 7.9 ± 0.82 with nonbrood feeder as 7.69 ± 0.29 and nonbrood-waterer 7.49 ± 0.65 (Tasistro et al., 2004). One would expect differences between the studies due to type of bedding. However, the absorbance of new wood shavings was measured at $1.88 \text{ g of H}_2\text{O/g of material}$ vs. $1.82 \text{ g of H}_2\text{O/g material}$ for unused rice hulls and the 2 were not statistically different for NH_3 generation in laboratory measurements on bedding/excreta mixtures (Miles et al., 2011b). Moreover, seasonal and house structure/management effects are likely the primary causes of differences between the studies. Type of waterer was not specified in the Tasistro et al. (2004) study.

Interpreting the Tasistro et al. (2004) results relative to the current study, we found a higher pH in the reused rice hulls vs. one growout on wood shavings, an expected result because litter pH tends to increase over time (Nahm, 2003). Tasistro et al. (2004) did not consistently show greater litter NH_3 at waterers at the end of the flock, whereas the current study shows significantly higher NH_3 at waterers during the mid-growout measurements. In addition, the cross-flow house had comparable feeder and higher waterer litter moisture contents with the current study. At the 45% litter moisture contents in the current study, the

increase in NH_3 at waterers is expected. Recent work reported maximum litter NH_3 volatilization between 42 and 46% litter moisture content for reused wood shavings litter (Miles et al., 2011c). Tasistro et al. (2004) stated that the litter moisture near waterers in that study (approximately 55%) was at the threshold of becoming anaerobic, which would cause NH_3 evolution to decrease.

More recent spatial studies provide mid-growout NH_3 flux with litter moisture content and pH throughout tunnel-ventilated broiler houses for wood shavings litter and from these respective flocks: 29 (summer), 13 (winter), 15 (winter), and 17 (summer) in commercial broiler houses in Mississippi (Miles et al., 2006b, 2008b, 2011a). In the first study (Miles et al., 2006b), brood vs. nonbrood half NH_3 flux indicated lower brood NH_3 flux (136 vs. $310 \text{ mg} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$) with somewhat lower pH (7.6 vs. 7.9) and litter moisture content (23.4 vs. 25.5%) during the 29th flock on reused litter. The second study, Miles et al. (2008b), which compared 2 commercial houses, reported litter moisture contents at 27 and 27.6%, pH at 8.24 and 8.51, and NH_3 flux at 412 and $294 \text{ mg} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$, respectively, during the 13th flock on reused litter. The most recent study (Miles et al., 2011a) reported similar values for whole-house litter pH, moisture content, and NH_3 flux as the 2 aforementioned studies. Although the data were presented as pooled for the entirety of the houses, color vario-grams indicated an effect of half-of-house management for some parameters (e.g., brood half litter temperature at the beginning of the flocks), but the effect was limited to NH_3 flux at the mid-growout. Miles et al. (2011a) measured a greater summer flux (522 vs. $278 \text{ mg} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ in winter) and an increased nonbrood flux (482 vs. $316 \text{ mg} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$). The latter study sampled litter and NH_3 flux at an equidistance between the feeders and waterers to capture gross trends in this area due to traffic and cake formation. At the mid-growout, the combined feeder/waterer samples were inconsistent with respect to high or low moisture content and did not appear different than surrounding samples for NH_3 flux. Like Tasistro et al. (2004) at the end of the growouts, the combined feeder/waterer samples exhibited lower NH_3 flux than surrounding samples, likely due to heavy cake forming a seal over the litter in those areas (Miles et al., 2011a).

The complexity and impact of cake formation has scarcely been discussed in the literature relative to gaseous emissions. Sistani et al. (2003) characterized the rate of cake production during 1 yr on 3 commercial farms and reported 57% of litter remained in the house after decaking between flocks. In pen trials, Coufal et al. (2006a) found that top dressing litter reduced cake production, but did not affect total litter production. With qualitative notes of litter condition at grid sampling sites, Miles et al. (2008b, 2011a) noted low NH_3 flux in caked areas near fans and feeder/waterer lines. In the current research, there was some cake formation; however, choosing the mid-flock measurement preclud-

ed the sealing effect that was noted in earlier spatial flux measurements.

Significant variability was found when comparing results of the present study with earlier reports of litter NH_3 , moisture content, and pH. This is not surprising when considering the dynamic confluence of factors affecting these parameters. Still, it is logical to make inferences based on housing characteristics and management practices. The present study is the first of its kind to specifically assess NH_3 generation at sidewalls, feeders, and waterers in modern commercial broiler houses during 6 flocks on reused litter. By sampling at mid-flock, intermittently during 2 yr (6 flocks total), the present study consistently demonstrated the effect of litter location at sidewalls, feeders, and waterers relative to potential for NH_3 generation and differences in moisture content, pH, and litter NH_4^+ . The effect of half of house was less pronounced, indicating lower NH_3 at feeders in the nonbrood area and higher pH at waterers there. With the greatest NH_3 volatilization and moisture content at waterers, the results suggest reducing litter moisture by approximately 20 to 25% under waterers can reduce NH_3 by 38 to 77%. Relative to the total NH_3 generated by the litter, partitioning the data attributed to each location indicates just more than half of the NH_3 can be expected near waterers (54–55%), whereas litter near sidewalls contributes 25 to 33% of the total NH_3 and litter near feeders contributes 13 to 20%. Litter between waterers on either side of the middle feeder/water set would need to be considered for developing mitigation strategies for the entire litter footprint. However, these findings support consideration of zone litter treatments near waterers during a growout.

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